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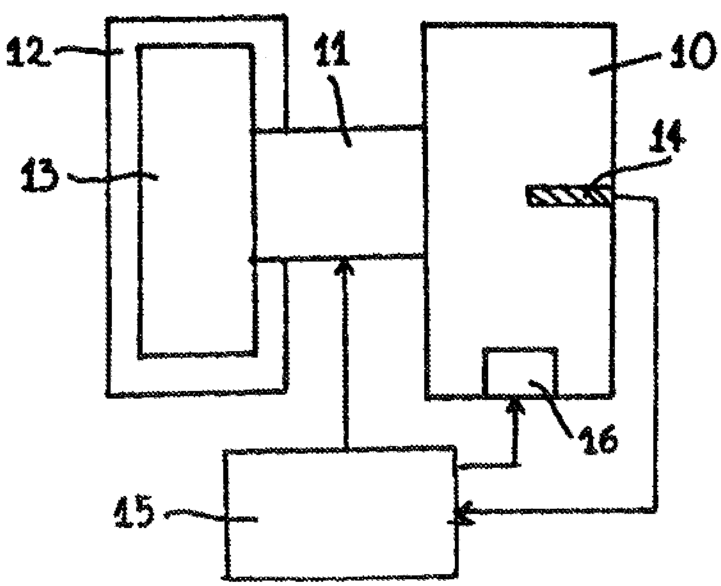

(57) Abstract

A thermoregulator consists of an insulated container (10) the temperature of the interior of which is controlled. The container is connected to a variable thermal bridge (11) which in turn is connected to a thermal capacitor (13) which may be an ice pack. A sensor (14) monitors the temperature of the container (10) and varies the thermal conductivity of the bridge (11) in dependence on the sensed temperature. As a thermal capacitor (13) is employed which requires no supply of power when in use, the only power needed is power to control the thermal bridge (11). This ensures the thermoregulator can be particularly convenient, efficient and portable.

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THERMOREGULATOR

The present invention relates to a thermoregulator and in particular a thermoregulator which is operable by means of variable insulation. The present invention is particularly suited though not exclusively to portable and benchtop applications.

Conventionally in order to control accurately the subambient temperature of containers such as sample vials apparatus employing conventional or peltier effect heat pumps have been used to pump heat in a controlled fashion from the temperature regulated zone. This heat plus the heat generated by performing this exercise is passed via a heat sink to the surrounding environment. In general the energy demand of such apparatus can be high and requires a large heat sink which makes it inconvenient for portable and benchtop applications. As an example of the energy demand of a conventional peltier based thermoregulator reference is made to Figure 1 which shows the characteristics of a peltier device; this shows the relationship between the current I drawn by a peltier device and the temperature difference ΔT across the peltier device. Hence for a well insulated container having a control temperature of -5°, operating in ambient conditions of 40°, having a heat sink at 55° and with the heat pumped from the container to maintain its temperature at -5° likely to be around 10 watts (Q); ΔT = -60° (Tpeltier(cold) - Tpeltier(hot)). From Figure 1 it may be seen that the current required to maintain this steady state condition will be around 7 A (point A on Figure 1). The peltier device characterised has a resistance of around 2.5Ω and so the power needed under these conditions would be around 130 watts and the heat sink required to transfer this heat to the environment is necessarily large.

The present invention seeks to overcome the disadvantages identified above with respect to conventional thermoregulating devices and seeks to provide a simple but accurately controllable thermoregulator which uses significantly less power and can be conveniently used in

portable and benchtop applications.

The present invention provides a thermoregulatory device comprising a temperature regulated zone; a temperature sensor for measuring the temperature of the zone; a removable thermal capacitor the temperature of which is lower than ambient temperature; adjustable control apparatus connected to the temperature sensor for transferring heat from the temperature controlled zone to the thermal capacitor in dependence on the sensed temperature of the temperature controlled zone.

Preferably the control apparatus is a thermal bridge between the thermal capacitor and the temperature controlled zone. The thermal bridge may be in the form of two thermally conductive arms, a first arm being connected to the thermal capacitor and a further arm being connected to the temperature controlled zone; and a connecting member movable from a position where the member is thermally isolated from at least one of the arms to a further position in which the member is in thermal contact with both of the arms. Alternatively, the thermal bridge may include a peltier device for controlling the flow of heat from the temperature controlled zone to the thermal capacitor. Another alternative is to regulate circulation of a fluid between the temperature control zone and the thermal capacitor.

Ideally the thermal capacitor is an ice pack containing a glycol or saline mixture in a frozen state as these can absorb relatively large amounts of energy. The temperature controlled zone may be the interior of an insulated container, for example an insulated aluminium block with recesses for sample vials or microtitre trays. Such an arrangement may particularly be used in containing and controlling the temperature of assays, especially field-based assays. Also the thermoregulatory device may be portable.

In a further aspect the present invention provides a method of controlling the temperature of a zone comprising the steps of measuring

the temperature of the zone with a sensor; determining in dependence on the measured temperature whether cooling of the zone is required; and where cooling is required, operating adjustable control apparatus to remove heat from the zone by altering the thermal insulation between the zone and a removable thermal capacitor.

Thus, with the present invention a thermoregulatory device and a method of controlling the temperature of a zone is provided in which the thermal capacitor is removable/replaceable and is connected via a bridge of variable thermal impedance to the zone to be cooled. Moreover, when in use the thermal capacitor does not require a supply of power to operate. Instead, power is only required to control the variable thermal bridge between the thermal capacitor and the zone to be cooled.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a graph of the relationship between the current drawn by a peltier device, the heat pumped across it and the temperature difference ΔT across which the heat is pumped;

Figure 2 is a block diagram of a thermoregulator in accordance with the present invention;

Figure 3 is a diagram of an embodiment of a thermoregulator in accordance with the present invention;

Figure 4 is a diagram of a further embodiment of a thermoregulator in accordance with the present invention;

Figures 5a and 5b are detailed diagrams of the fluid cell of Figure 4;

Figures 6a and 6b are diagrams of a further alternative thermal bridge for use with the thermoregulator of Figure 2; and

Figures 7a and 7b are diagrams of an even further alternative thermal bridge for use with the thermoregulator of Figure 2.

With reference to Figure 2, the thermoregulator consists of an

insulated container 10 the temperature of the interior of which is to be controlled. The container 10 is connected to a variable thermal bridge 11 which in turn is connected to a thermally insulating sleeve 12 adapted to hold an ice pack 13 or other thermal capacitor. Naturally the sleeve 12 is shaped to hold whatever size of ice pack 13 it is intended to employ. A temperature sensor 14 is provided in the container 10 to monitor the temperature within the container. The sensor 14 is also connected to a controller 15 which monitors the output from the sensor 14 and controls the operation of the variable thermal bridge 11. The controller 15 is a dedicated electronic device and may be powered from a rechargeable power source. Additionally an electrical heating element 16 may be inserted into the container 10, this is powered as necessary by the controller 15.

The variable thermal bridge 11 acts to restrict the flow of heat from the container 10 and thus functions as a variable insulator. In its simplest form it may be a switch which in its closed state prevents heat flowing from the container 10 and in its open state enables heat to flow from the container. In this way the temperature of the interior of the container is controlled. In practice though the thermal bridge usually does not operate in only two modes but instead has more than two states of operation which may be either discrete or continuously variable. The flow of heat from the container 10 may be controlled either by conduction or forced convection. For temperature control close to or above ambient temperature the electrical heating element 16 is employed enabling fine temperature control; this is particularly useful when operation is required in variable ambient conditions.

In one embodiment of the thermoregulator the thermal bridge is in the form of a conventional peltier device which connects the ice pack 13 and the container 10. By utilising a peltier device accurate control of the temperature of the interior of the container may be achieved. It should

be borne in mind though that the primary function of the peltier device in the thermoregulator described is that of a controllable variable insulator rather than as a cooling device since the cooling is performed by the ice pack.

As a result of the different function performed by the peltier device and the fact that the peltier device is in thermal contact with the ice pack, the power needed to operate the peltier device is significantly less than in conventional peltier cooling apparatus. This can be shown with reference to Figure 1. Taking the same desired temperature of the container as in the former example, -5° and assuming the ice pack to be at a temperature of -8°, ΔT now becomes +4°. This means that with a heat extraction of 10 watts as before the peltier device can operate drawing a current of only 0.5 A which corresponds to around 0.6 watts (point B in Figure 1). This may be explained by the fact that the greater power needed with the conventional peltier device described earlier corresponds to the energy needed to pump small amounts of heat across a large temperature gradient. Whereas with the thermoregulator described above with reference to Figure 2, the greater amount of energy was extracted from the ice pack separately in a deep freeze.

In addition, the thermoregulator of Figure 2 does not require the large heat sinks conventionally used to transfer the pumped and generated heat to the surroundings and so the size of the thermoregulator can be greatly reduced.

The peltier device which forms the thermal bridge 11 may also be operated in a way which provides additional cooling to the insulated container and enables the container to be cooled to temperatures below the temperature of the ice pack. Here again since most of the cooling is performed by the ice pack the energy needed to achieve such lower temperatures is much less than would conventionally be the case.

It will of course be appreciated that alternative electrical

devices can be used in the thermal bridge to control the insulation of the ice pack with respect to the container.

Alternatively, the thermal bridge 11 may be mechanical in operation and an example of a thermoregulator utilising a mechanical thermal bridge is shown in Figure 3. As may be seen both the container 10 and the sleeve 12 have fixed connecting arms 17a, 17b respectively which are made of a good thermally conductive material such as brass. Each of the arms 17a, 17b includes a threaded hole for receiving a threaded slug 18 which may also be of brass, the opposite end of which is connected to a servo motor 19.

When in use, the ice pack 13 is thermally isolated from the container 10 when the slug 18 is not in contact with both of the connecting arms 17a, 17b. If the temperature sensor 14 detects a temperature within the container 10 which is higher than the desired temperature, the controller 15 actuates operation of the motor 19 to rotate the slug 18 forwards (which is upwards in Figure 2). The threads on the surface of the slug 18 which engage with the threads in the hole of the connecting arm 17a of the container passes through the hole and then engages in the threaded hole of the connecting arm 17b of the ice pack 13. The slug 18 includes contact discs 18', 18" which cooperate with microswitches or contacts (not shown) on the arm 17a to halt operation of the motor 19 once the slug 18 is in the desired position. Thus once the slug 18 thermally connects the ice pack 13 and the container 10 the lower control disc 18' is brought into contact with its respective contact causing the motor to stop with the thermal bridge between the ice pack and the container established. At this point with the ice pack 13 and the container 10 in thermal contact, a flow of heat from the container to the ice pack ensues as a result of the difference in temperature. This flow of heat continues until the desired temperature of the interior of the container is reached.

When the temperature of the interior of the container

detected by the sensor 14 is the desired temperature the controller 15 causes the motor 19 to rotate the slug 18 in the opposite direction thereby breaking the thermal connection between the ice pack and the container. Once the slug 18 is free from the arm 17b, the upper disc 18" is brought into contact with its respective contact causing the motor 19 to stop. These actions are repeated as necessary to retain the temperature of the container at the desired temperature.

An alternative electromechanical thermoregulator which utilises convection rather than conduction for temperature control is shown in Figures 4, 5a and 5b. In this embodiment the container 10 is connected to one end of a fluid filled tank 20 through a thermally conductive plate 21. Similarly, the sleeve 12 containing the ice pack 13 is connected to an opposing side of the fluid filled tank 20 through a further thermally conductive end plate 22. A permanent magnet 23 is located within the tank 20 and is moulded into a lightweight foam cylinder 24 also located within the tank. The cylinder 24 is mounted in a manner which enables the cylinder to rotate. Around the outside of the tank 20 electrical windings 25 are provided which are controlled by the controller 15. The tank 20 is filled for example with dilute glycol or air.

In use, the windings 25 are energised by the controller 15 to cause the cylinder 24 to rotate which enables good heat transfer between the container 10 and the ice pack 13. When the cylinder is stationary only limited heat transfer occurs. Since the speed of rotation of the cylinder is continuously variable so the extent of heat transfer is continuously variable. Very little power is required to drive the rotating cylinder 24 whilst still providing an efficient On/Off ratio and very good conductivity. Also, with this arrangement no mechanical end stops such as microswitches are required. The arrangement is particularly suited for use as small laboratory fermenters.

In addition to the above an alternative convective

thermoregulator employs a fluid, for example air or glycol with a fan or pump which is used to circulate the fluid between the ice pack 13 and the container 10.

In Figures 6a and 6b a linear tapered cone thermal bridge is shown for thermally connecting the container to the ice pack. A thermal bridge slug 30 is located on a threaded drive shaft 31 which passes through an aluminium tufnol block 32 which has a substantially conical recess for receiving the slug 30. The drive shaft 31 is thermally insulated at its end distant from the slug 30 so as to reduce any possible thermal conduction by the shaft. The shaft 31 is driven by a low torque motor enabling the slug 30 to be moved into and out of the recess in the block 32. The recess or cavity is packed with a high viscosity grease which does not substantially dissipate over time. With this arrangement actuation of the slug may be by detection of a current surge on the drive motor to determine the On position. It may not be necessary to detect the Off position as a 2mm movement of the slug can be adequate to achieve a 5:1 conductivity ratio.

Turning now to Figures 7a and 7b, a rotary cylinder thermal bridge is shown. The thermal bridge cylinder 33 is constructed from aluminium tufnol sandwiched either side by aluminium. The cylinder 33 is mounted on a central thermally insulated drive shaft 34. The solid cylinder 33 is located in a block 35 which is similarly constructed of a sandwich of aluminium tufnol and aluminium. When the tufnol layers of the cylinder 33 and block 35 are aligned the icepack side 22 and the block side 21 are thermally insulated from one another. When the cylinder 33 is driven and rotates up to 90°, the ice pack side 22 and block side 21 are brought into thermal contact. The whole thermal bridge is encapsulated in insulating end plates 36 and filled with a low viscosity thermal grease.

The thermal bridge can be actuated using a low torque geared server motor or a solenoid. With a solenoid positional sensing of

the cylinder is implicit and no end stop protectors are required. With a server motor microswitches operating as end stops may be necessary.

In all of the embodiments described above a thermal capacitor such as an ice pack is used to remove heat from the insulated container to be cooled. Of course other types of thermal capacitors may be used instead of the ice pack but whatever type of device is used in all cases the device should have a large thermal capacity. An ice pack is seen as particularly suited to the thermoregulators described above since it uses both the latent heat energy and heat capacity of a fluid such as a glycol mix. Additionally such ice packs are readily available and portable.

Also, although reference has been made to a container 10 this is intended as a general reference to an identifiable area or zone the temperature of which is to be controlled.

As has been shown the thermoregulator described above enables accurate control of the temperature of the zone without requiring large amounts of energy and without the large heat sinks conventionally included in cooling devices. This enables the thermoregulators of the present invention to be much smaller in size rendering them suited to portable and benchtop applications. In the case of portable applications the reduction in the energy needed to operate the thermoregulator enables the thermoregulator to be powered by rechargeable batteries.

One application of the present invention is in the temperature control of assays and especially field-based assays. It is important that assays be kept at an exact temperature to ensure reproducibility of results. This has formerly been difficult to achieve with field-based assays since conventional peltier effect cooling devices can be heavy and need an external power supply making them unsuitable for portable applications. With the present invention though accurate control of the temperature of assays can be achieved with a fully portable thermoregulator.

The thermoregulators of the present invention have the

additional benefits that the initial cooling of the zone to the desired temperature can be achieved much more quickly than with conventional cooling devices. Also, the length of time of continuous operation of the thermoregulators, which is limited by the lifetime of the ice pack, is greater than with conventional ice pack based cooling devices which lack the variable insulation of the present invention.

It will be understood from the above that in addition to the different embodiments described above a number of ways are envisaged in which the thermoregulator can be arranged to control the degree of thermal insulation between the temperature controlled zone and the thermal capacitor without departing from the spirit and scope of the present invention.

CLAIMS

1. A thermoregulatory device comprising a temperature regulated zone; a temperature sensor for measuring the temperature of the zone; a removable thermal capacitor the temperature of which is lower than ambient temperature; adjustable control apparatus connected to the temperature sensor for transferring heat from the temperature controlled zone to the thermal capacitor in dependence on the sensed temperature of the temperature controlled zone.

2. A thermoregulatory device as claimed in claim 1, wherein the adjustable control apparatus is a thermal bridge between the thermal capacitor and the temperature controlled zone.

3. A thermoregulatory device as claimed in claim 2, wherein the thermal bridge is in the form of two thermally conductive arms, a first arm being connected to the thermal capacitor and a further arm being connected to the temperature controlled zone; and a connecting member movable from a position where the member is thermally isolated from at least one of the arms to a further position in which the member is in thermal contact with both of the arms.

4. A thermoregulatory device as claimed in claim 3, wherein the connecting member is driven by a motor.

5. A thermoregulatory device as claimed in claim 2, wherein the thermal bridge includes a peltier device for controlling the flow of heat from the temperature controlled zone to the thermal capacitor.

6. A thermoregulatory device as claimed in claim 1, wherein the adjustable control apparatus is a fan arranged to regulate circulation of a fluid between the temperature controlled zone and the thermal capacitor.

7. A thermoregulatory device as claimed in any one of the preceding claims, wherein the temperature controlled zone is the interior of an insulated container.

8. A thermoregulatory device as claimed in claim 7, wherein the insulated container is adapted to hold assays.

9. A thermoregulatory device as claimed in any one of the preceding claims, wherein the thermal capacitor is an ice pack.

10. A thermoregulatory device as claimed in any one of the preceding claims wherein the device is portable.

11. A method of controlling the temperature of a zone comprising the steps of measuring the temperature of the zone with a sensor; determining in dependence on the measured temperature whether cooling of the zone is required; and where cooling is required, operating adjustable control apparatus to remove heat from the zone by altering the thermal insulation between the zone and a removable thermal capacitor.

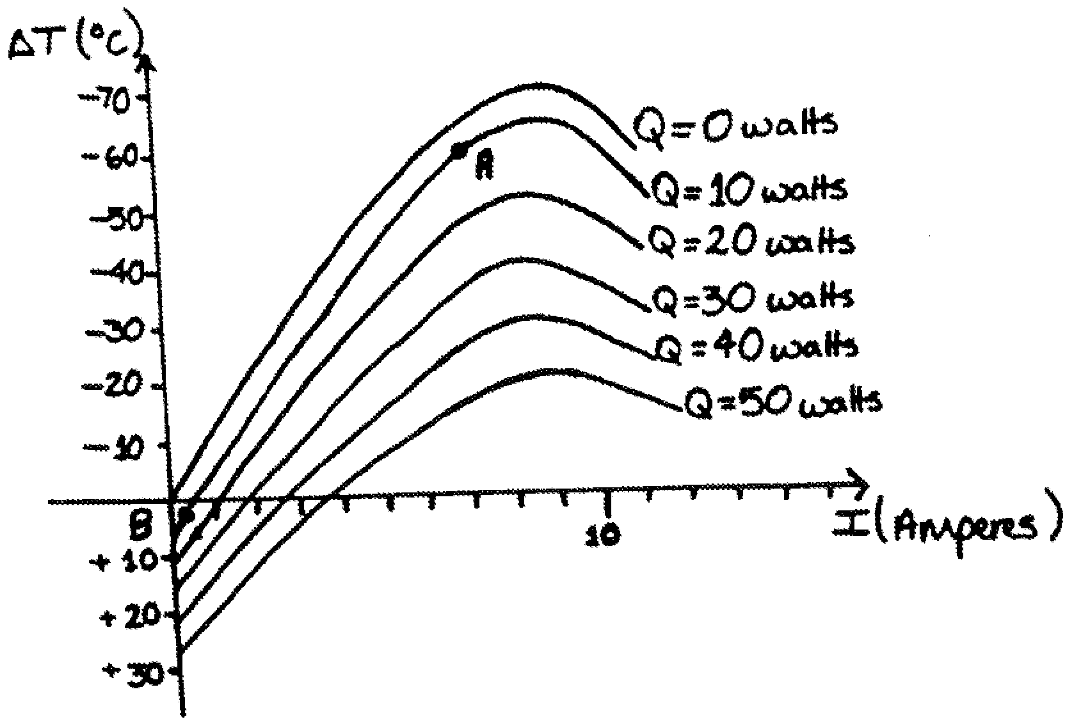

FIGURE 1

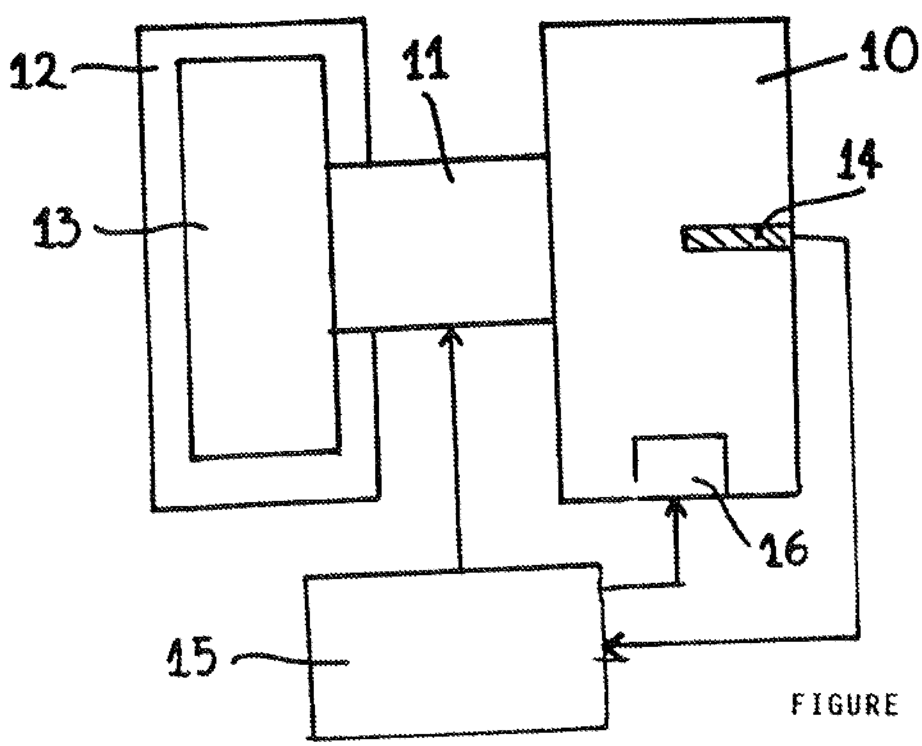

FIGURE 2

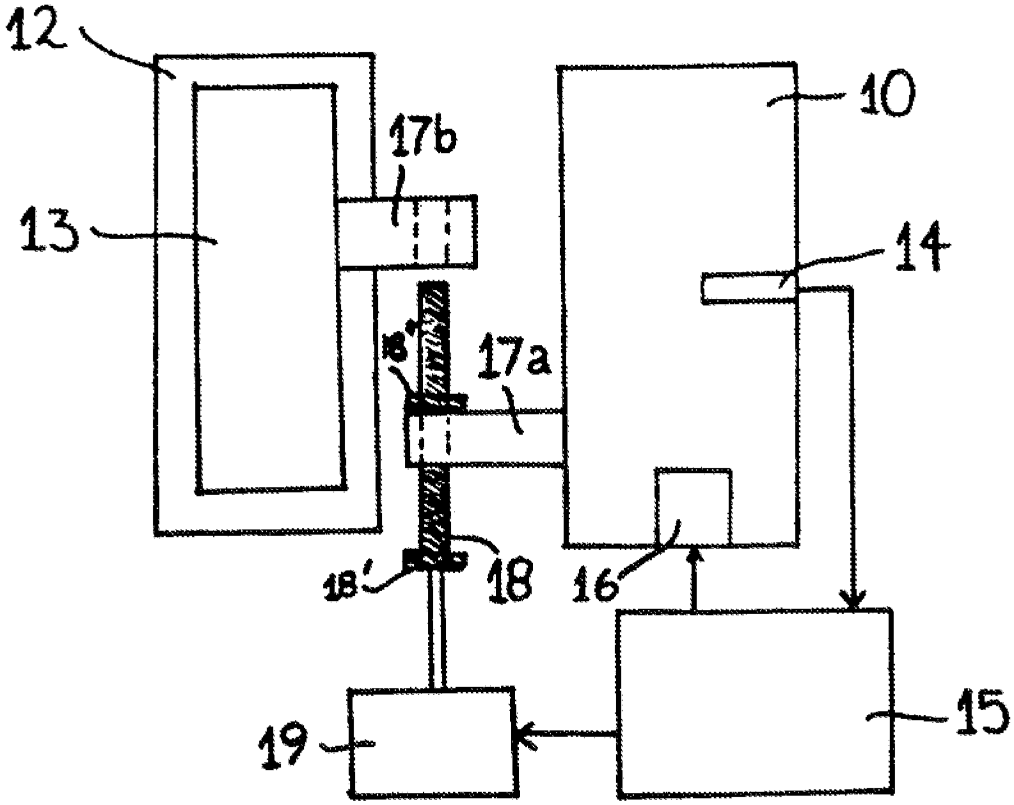

FIGURE 3

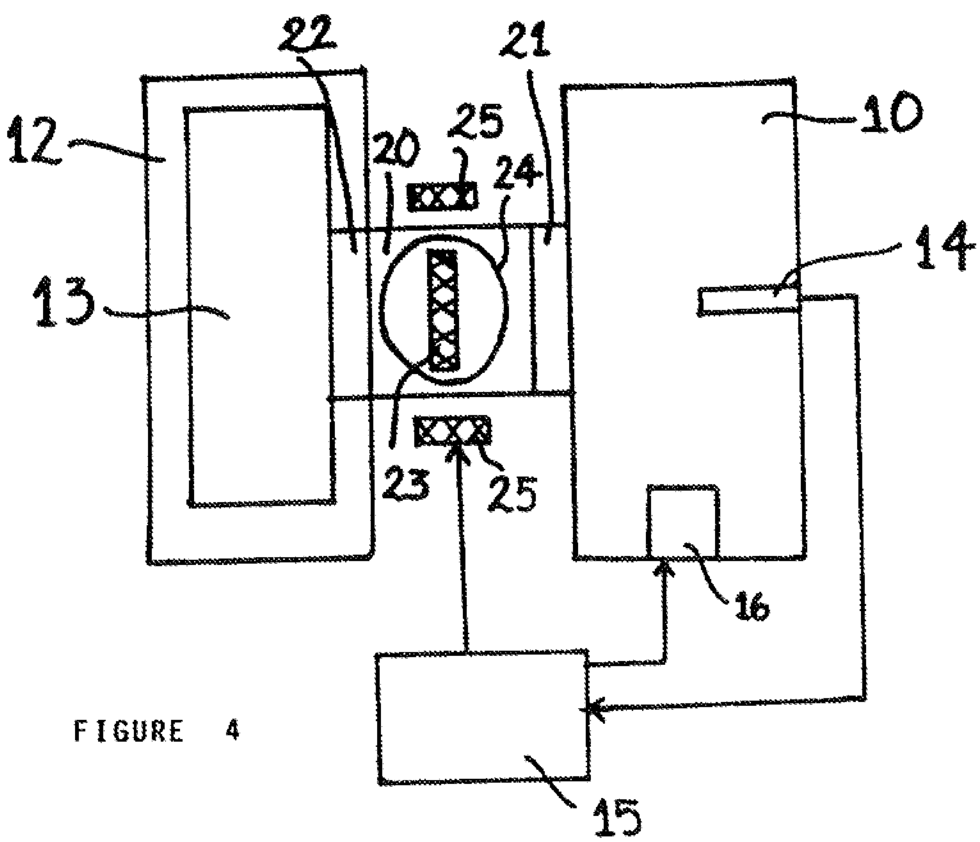

FIGURE 4

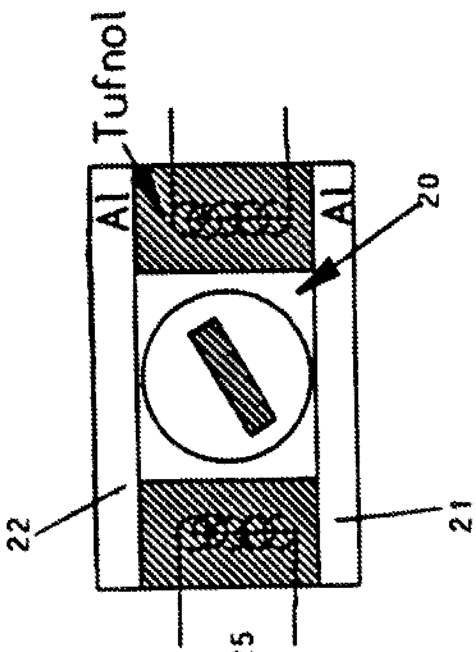

FIGURE 5a

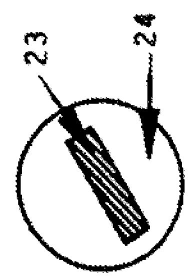

FIGURE 5b

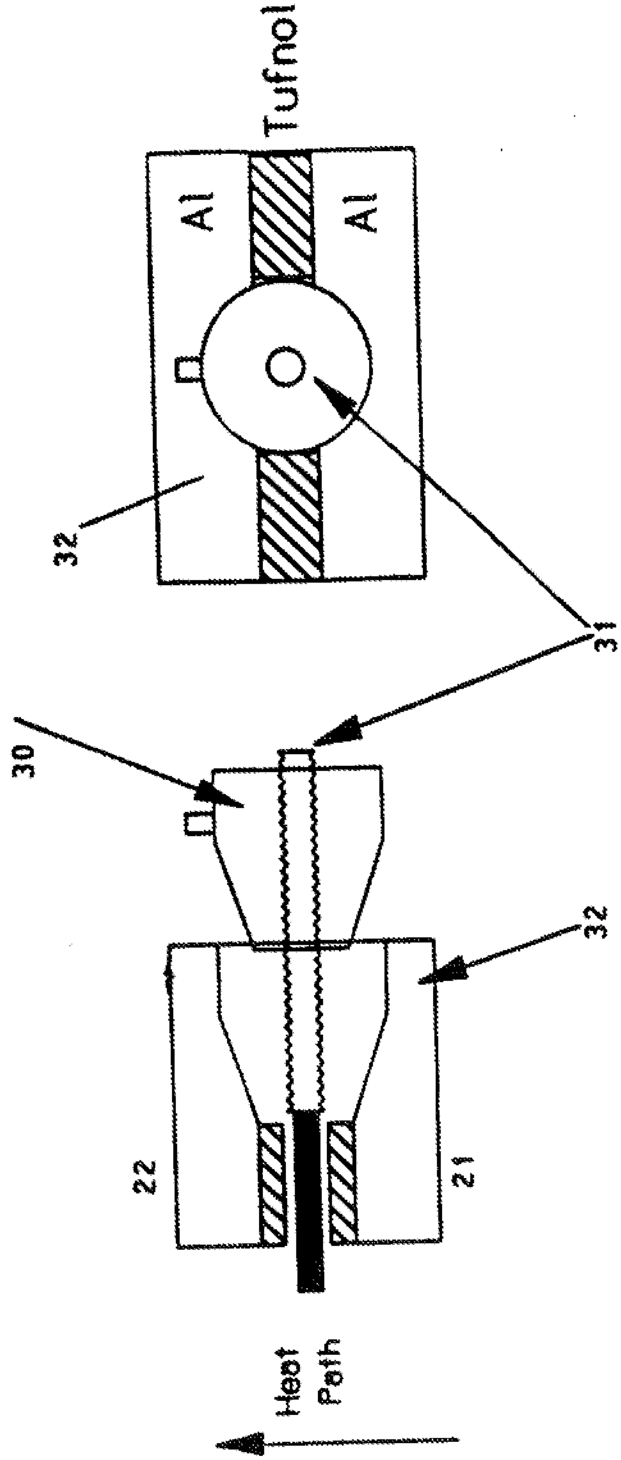

FIGURE 6a

FIGURE 6b

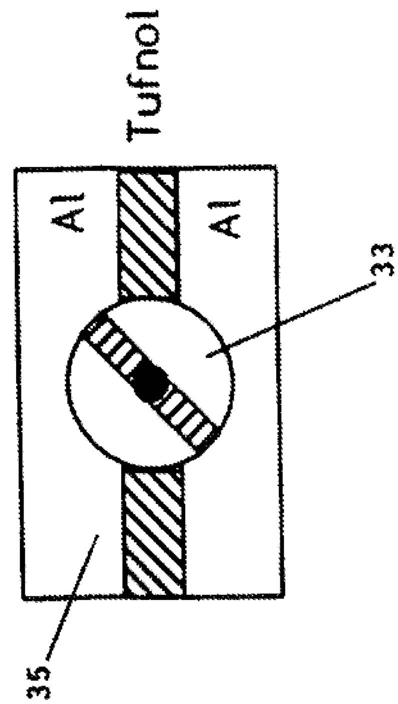

FIGURE 7b

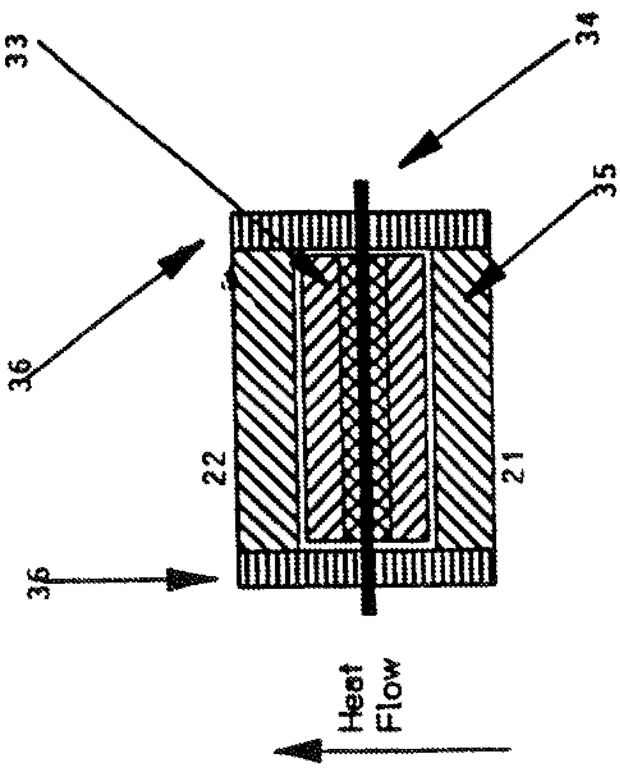

FIGURE 7a

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/00135

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G05D23/19 B01L7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G05D B01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,4 370 547 (C. WARD) 25 January 1983 see column 3, line 8 - line 50; figure 2 ---	1-3,11
X	DE,A,41 26 227 (ANT NACHRICHTENTECHNIK GMBH) 11 February 1993 see column 1, line 64 - column 2, line 28; figures 1,2 ---	1,4,11
X	GB,A,2 111 301 (GEORG MAY) 29 June 1983 see abstract see page 4, line 16 - line 61; figures 1,2,9,10 ---	1,2,5,10,11
X	WO,A,89 09437 (P. DEAN) 5 October 1989 see page 8, last paragraph - page 9, last line; figure 4A ---	1,4,11

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
15 March 1996	12.04.96

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,3 712 268 (J. REED) 23 January 1973 see abstract see column 2, line 62 - column 4, line 50; figures 1,4 ---	1,5,7,8,10,11
X	EP,A,0 236 069 (CETUS CORORATION) 9 September 1987 see page 8, line 20 - page 13, line 32; figures 1-3 ---	1,5,11
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